THE PURIFICATION OF WATER BY ANHYDROUS CHLORINE.

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In June, 1910, the writer began a series of experiments with the object of determining the availability of commercial liquefied chlorine for the purification of water. It is believed that the use of chlorine in the gaseous form and dry state had not been used or proposed for the purification of domestic water supplies before that time. Previously chlorine as a purifying agent had been added to the water as "chlorine water" or as a solution of one of the hypochlorites; dry gaseous chlorine had not been directly applied to the water to be purified.

It was recognized that if an apparatus could be devised for accurately dosing the water with the dry gas, the method would be much superior to those using hypochlorites or chlorine water, because of the uniform strength of the purified, dry, compressed gas. It is well known that the hypochlorites are unstable compounds and the content of "available chlorine" is uncertain. This necessitates frequent examinations in order to determine the quantity to be used. Another objection to the use of hypochlorites is that more or less troublesome dosing devices must be used. It has also been found that a slight excess of the hypochlorites imparts a disagreeable taste and unpleasant odor to the water.

At the present time chlorine is made in large quantities by the electrolysis of salt. In fact it is a by-product in the manufacture of caustic soda. Most of the chlorine so obtained is used to make calcium hypochlorite and other hypochlorites, but a considerable quantity is purified, dried, liquefied by pressure, and put on the market in steel drums or cylinders holding from 100 to 140 pounds each. This chlorine is almost chemically pure, containing nothing except traces of oxygen, carbon dioxide, and nitrogen. In putting up chlorine in this way all water vapor must be removed in order to prevent corrosion of the steel used in the construction of the storage drums. The pressure of this liquefied chlorine on the walls of the drum varies from 54 pounds per square inch at 32°F. to 216 pounds at 122°F.

The price of liquefied chlorine varies from fifteen to twelve cents per pound, depending on the quantity. I have been informed by producers, however, that it is probable, if the demand for it should grow, that the price would soon be much less than it is at present.

From the Chemical Laboratory, Army Medical School.

It may be well, before proceeding further, to briefly state certain properties of chlorine which have a direct bearing on its application as a purifying agent for water.

1. Chlorine is an elementary gas having a strong affinity for hydrogen.

2. It attacks metals, but (with some exceptions) only in the presence of water or other compound, from which, by appropriating hydrogen, it can liberate oxygen. This oxygen is the corroding agent. Hence *dry* chlorine can be kept in steel drums indefinitely and may be conducted through iron, brass, or copper pipes, and valves without undue corrosion, provided water and water vapor (moist air) are excluded therefrom.

3. Its sterilizing action, so far as water purification is concerned, is conceded to be due, not to the chlorine itself, but to the action of nascent oxygen, the result of the abstraction of hydrogen from some of the water molecules by the chlorine. This liberation of oxygen may be shown by the following equation, which, however, expresses only the final reaction and not the intermediate reactions which may take place as a result of the interaction of chlorine and water:

$$2\ Cl + H_2O = 2\ HCl + O.$$

The oxygen atom is most active immediately after it is liberated. If it does not soon find other suitable matter to combine with, it becomes joined to another free oxygen atom, the two forming a stable molecule. This can be demonstrated by conducting a little chlorine into a beaker of water and testing from time to time with iodized starch (starch paste and iodide of potassium). At first a blue color is developed, but as time elapses the test shows a fainter blue until finally no reaction is manifest. This is because the oxygen, at first nascent and capable of liberating the iodine, has resumed its normal condition. Bearing this fact in mind, it would appear reasonable to assume, therefore, that to obtain the maximum oxidizing effect of the chlorine it should be conducted, in its gaseous condition, directly to the water to be purified. This, however, has not been the usual practice either for chlorine or the hypochlorites. Chlorine in the past has been used as chlorine water, while the hypochlorites are first mixed with water and the resulting chlorinated water is then added in proper quantity to the water to be purified. When used in this way much of the oxidizing effect of the nascent oxygen is lost.

4. Water at ordinary temperature will absorb about two volumes of chlorine. This is equivalent to about 4000 parts per million by weight.

This ready solubility of chlorine is of great importance in water purification, since it makes it unnecessary to use the elaborate mixing devices which would be required were the chlorine not easily soluble in water.

QUANTITY OF CHLORINE REQUIRED FOR PURIFYING WATER.

In practice, the quantity of chlorine required depends entirely upon the amount of oxidizable impurities in the water. These oxidizable substances may be inorganic or organic; and the latter may be either living or dead.

Water of low organic content, as shown by its "oxygen consumed" value, will require less chlorine than water showing a higher value. This is also true of other processes based on oxidation, notably the hypochlorite process, and the ozone process.

In general, it may be said that with an average unfiltered river water such as that of the Potomac, about one-half of a part (by weight) of chlorine gas per million of water will be required. For clear lake waters three-tenths to four-tenths of a part per million will be sufficient. That is to say, it will require from three to four pounds of liquid chlorine for a million gallons of water of average purity.

CHANGES PRODUCED IN WATER BY CHLORINE USED AS A PURIFYING AGENT.

1. Chlorine reduces the quantity of the organic and other oxidizable substances contained in the water, or removes them entirely, as the diminished oxygen consuming value of the water shows.

2. By the interaction of chlorine and water a relatively minute quantity of hydrochloric acid is produced. The hydrochloric acid thus formed is neutralized by the carbonate of lime normally present in the water, forming chloride of lime at the expense of a small portion of the carbonate.

3. Oxygen is liberated. A part of this nascent oxygen combines with the oxidizable impurities of the water, while the rest resumes its normal state and either remains dissolved in the water or escapes.

4. Physical changes.

(*a*) *Taste.*—When used in proper quantity pure chlorine imparts no taste whatever to water purified by it. At least two parts of chlorine per million (four times the quantity necessary to sterilize) must be added before even the slightest change in taste can be distinguished in Potomac River water. It is probable however, that the disagreeable taste imparted to certain waters by chlorine or hypochlorites is due not to the chlorine *per se* but to the products formed by the oxidation of organic matter contained in the water.

(*b*) *Odor.*—The purified chlorine must be used in excess before it imparts an odor of chlorine to the water. Even when sufficient chlorine is used to impart a taste to the water the odor soon disappears and is at no time unpleasant.

It will thus be seen that the chemical composition and physical character of the water are practically unaffected by the use of chlorine, limited in quantity to a reasonable excess over that required for purification.

(*c*) *Length of Time of Contact.*—The experiments made in the chemical laboratory of the Army Medical School, indicate that the purifying action of dry chlorine gas, when applied to Potomac River water, is practically instantaneous. If particulate matter in which bacteria are imbedded is in the water, the action of the chlorine is not so rapid, time being required for it to penetrate the particles. Furthermore, certain bacteria, or rather spores, notably of *Bacillus subtilis*, resist the action of chlorine even in large amounts and after long contact. As much as six parts of chlorine per million will not destroy all spores of *Bacillus subtilis*, when that organism is present in large numbers.

As the time required to kill the pathogenic bacteria is so brief, no provision is made for prolonged contact in the apparatus presently to be described. The water merely flows through it, absorbing chlorine in its passage, and may be used immediately on discharge.

SUPERIORITY OF LIQUEFIED CHLORINE AS A PURIFYING AGENT FOR WATER.

1. It is superior to hypochlorites in the following respects:

(a) It is of uniform composition and may be supplied by a simple apparatus, to the water in unvarying, predetermined quantity, adjusted to the requirements of the water under treatment. Hypochlorites rapidly deteriorate when exposed to moist air and must be tested frequently. Furthermore, it is difficult to adjust the quantity with certainty.

(b) Liquefied chlorine gas used in proper quantity imparts neither taste nor odor to the water, while a slight excess of the hypochlorites makes the water unfit for domestic use.

2. It is superior to ozone because:

(a) It is much cheaper.

(b) It is easier to apply chlorine than ozone. Chlorine, because of its great affinity for, and solubility in, water requires no elaborate and complicated mixing apparatus; mere contact over a comparatively small surface of the flowing water is sufficient. The water in its passage absorbs the gas and is further mixed in its onward flow through the pipe, conduit, or aqueduct.

DESCRIPTION OF CHLORINE WATER PURIFYING APPARATUS.

The apparatus described below was developed as a result of much experimentation and is believed to satisfactorily solve the problem of purification of water by chlorine gas. It consists of the following parts:

1. A pressure-reducing mechanism for reducing the high pressure of the compressed chlorine to a uniform low pressure, so that it may be possible to supply it to the water in uniform quantity.
2. A current reducing and regulating device placed between the pressure-reducing mechanism and the mixing chamber.
3. A mixing or absorbing chamber into which the chlorine is conducted, and through which the water to be purified flows.
4. A mechanism which automatically starts the flow of gas into the mixing chamber when the water is turned on and arrests the flow of gas when the water is turned off.

Referring to the diagram (page 788), 1 represents a tank, reservoir, standpipe, or other container in which a fairly constant water level is maintained.

The pipe 2 with a valve 3 leads from the reservoir and is continuous with another pipe 5 having a water-seal at 6 and a valve at 4. In operation the valve 3 is set so that it will deliver less water than pipe 5 and valve 4 are capable of conducting, so that pipe 5 is only partially filled with water. This pipe 5 constitutes the absorbing chamber into which the chlorine is conducted through the tube 36.

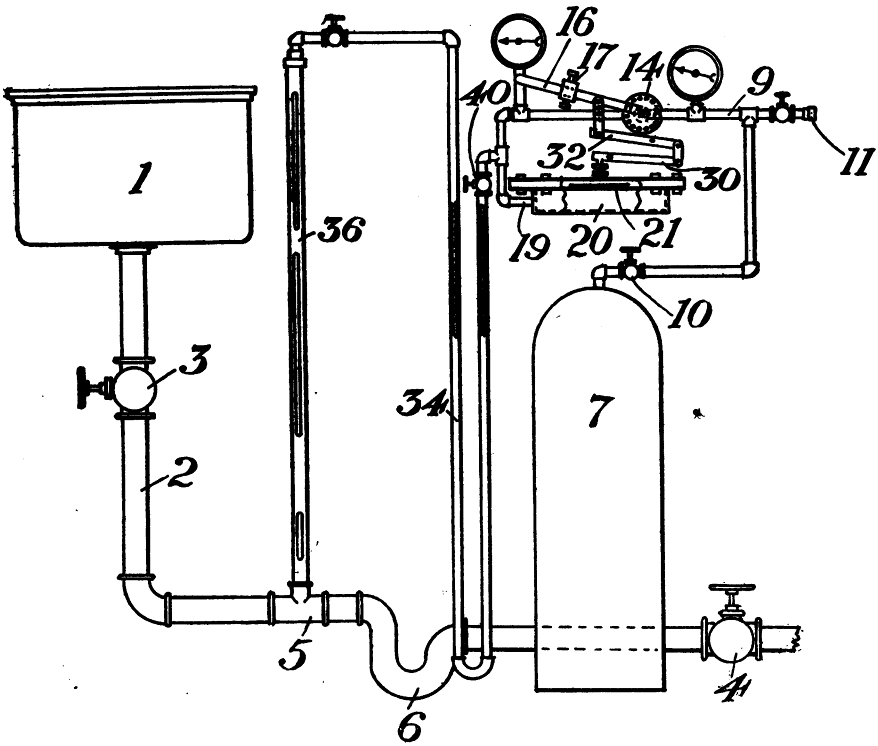
A drum 7 contains the compressed chlorine, and at 11 is shown a connection for attaching another drum, if it is desired to do so. A metallic gas receiver 20 is connected with the drum or drums by the pipes 9 and 19. The top of this receiver is a thin metallic sheet 21, to which is attached a set of multiplying or amplifying levers 30, 32, 16. One end of the lever 16 is attached to the stem of the valve 14, while the other end is provided with a movable weight 17.

At 40 in the chlorine pipe is shown another valve. In a large apparatus in which much chlorine is used the amount may be regulated by this valve, but where the quantity of chlorine required is small, say sufficient for an apparatus with a capacity of only 40,000 gallons of water per hour or less, it is better to employ some device less likely to be plugged up by dust, rust, etc., than would be the valve with such a minute opening. This is done by opening valve 40 to its limit and interposing resistance in the "U" tube 34 by partly filling it with sand, powdered glass, or other material not acted on by chlorine. The resistance can be changed by using material of suitable size and varying the depth of it in the tube. From the tube 34 the chlorine passes through tube 36 into the absorbing or mixing chamber 5.

OPERATION.

When valve 10 of the chlorine drum is opened, chlorine passes through tube 9 and valve 14 into pipe 19, gas receiver 20, and resistance tube 34. Because of the resistance offered by the sand in the tube, the pressure in the receiver 20 rises and lifts the diaphragm 21, and the levers operated by it, and closes valve 14. As the gas passes through the sand in tube 34 the pressure in chamber 20 falls and the levers descend, opening valve 14, thus permitting more gas to pass.

CHLORINE WATER PURIFYING APPARATUS.



1. Reservoir.
2. Water Supply Pipe.
3. Water-regulating Valve.
4. Discharge Valve of Mixer.
5. Mixing Chamber.
6. Water Seal.
7. Chlorine Drum.
9–19. Chlorine Pipe.
10. Chlorine Drum Valve.
11. Connection for Another Drum.
14. Chlorine-regulating Valve.
16. Lever Attached to Chlorine Valve.
17. Weight to Regulate Working Pressure of Chlorine.
20. Metallic Chlorine Receiver.
21. Metallic Diaphragm.
30–32. Amplifying Levers.
34. Resistance Tube.
36. Chlorine Supply Pipe.
40. Valve.

Valve 4 in the main 5 being open, the water will flow through the mixing chamber 5, and as it comes into contact with the chlorine will absorb it. The chlorine and water are further mixed in their passage through water seal 6 and the main beyond. The purified water is discharged through valve 4. The quantity of chlorine going to the water may be regulated by shifting the weight 17 on the lever 16.

Once adjusted, the quantity of chlorine delivered by the apparatus in a given time will be constant, for it flows under a constant uniform pressure. The quantity of water flowing through the mixing chamber 5 will also be constant for a given time, since it is under a constant head. Therefore, by adjusting the flow of chlorine to the flow of water, a practically uniform mixture of the two may be attained.

It may be stated here, that in practice the quantity of chlorine necessary to purify a water is determined by testing the flow from valve 4 with a mixture of starch paste and iodide of potassium. The apparatus should be so adjusted that the water shows a sky blue color when it flows into a white dish or cup containing a few drops of the test mixture.

Automatic Chlorine Cut-off.—If valve 4 be closed, the flow of water in pipe 5 will be arrested, and the back pressure will cause it to rise in pipe 36 and stop the flow of chlorine. When valve 4 is opened the water in pipe 36 will flow out and the supply of chlorine will be re-established.

Of course this form of apparatus is only one of several that may be used; it is described here merely to illustrate the application of the process of purifying water by chlorine.

DATA RELATING TO THE PRACTICAL APPLICATION OF THE CHLORINE METHOD.

There is now in the Chemical Laboratory of the Army Medical School a small apparatus constructed on the lines shown in the diagram. This apparatus has a capacity of about 800 gallons per hour, occupies very little space, and weighs less than 200 pounds. The chlorine feeding and regulating mechanism of this small apparatus, with a few minor alterations, is large enough to supply chlorine for a mixer having a capacity of 1,000,000 gallons per hour. This particular apparatus has been in use now for more than six months and has given no trouble whatever. The process is believed to be applicable for use in purifying water supplies for cities, towns, factories, hospitals, etc.

1. Cost of installation of plant.

For cities already having aqueducts, reservoirs, pumping machinery, etc., this item would be very small. The mixing chambers, may be constructed of concrete, iron, terra cotta, or other suitable material. In some cases it may be feasible to utilize an aqueduct itself as a mixing chamber.

It may be well to state here that a mixing chamber sixteen inches in diameter and twenty-four feet long has a capacity of 750,000 gallons per day, while one thirty-two inches in diameter and fifty feet long has a capacity of 3,000,000 gallons. In order to convey an idea of the size of plant necessary, it may be said that to purify 750,000,000 of gallons per day (the quantity furnished greater New York), sixteen mixing chambers ten feet in diameter and two hundred feet long would be required. These would occupy about one acre of ground.

2. Cost of labor.

The item for extra labor would be trifling in amount for small or large plants. In the former all labor could be performed by the men operating the pumping machinery already in use; while in very large plants only one mechanic to look after the chlorine feeding apparatus, and a man or two to change the chlorine drums as they become exhausted, would be necessary.

A one hundred and forty pound drum of chlorine is sufficient for, say, 35 to 45 million gallons of water; therefore, by using a number of drums simultaneously frequent changes would not be necessary.

3. Cost of chlorine.

This will range from about thirty-six cents to fifty cents per million gallons of water treated, depending of course upon the quantity of chlorine used. As stated elsewhere in this paper, chlorine costs about twelve cents per pound and waters containing only a moderate amount of oxidizable impurities will require from three to four pounds per million gallons.

EFFICIENCY OF THE METHOD.

A working model of the apparatus with a capacity of 500 gallons per hour having been constructed, the writer, early in January, 1911, reported to the Surgeon General of the Army the results of the experiments made with chlorine and requested that the method be examined to determine its availability for use in the military service.

By order of the Secretary of War, this investigation was undertaken by a board of officers appointed in 1909 to investigate and make recommendations in regard to water supply and sewage disposal for permanent military posts, etc. The investigations of this board began early in February and continued until May, the report of the results being made by the board June 1, 1911.

The first series of efficiency tests was made at the pumping station at Fort Myer, Va. As stated by the board in its report: "The Board determined that in order to procure a typical water for experimentation which was somewhat polluted and had not been purified by filtration, the apparatus should be installed at the pump house of the intake of the Fort Myer water supply." The apparatus was accordingly set up by the side of the mechanical filter and operated continuously (day and night) for two weeks.

Table No. 1 shows the results of this series of tests:

TABLE I.

RESULT OF EXAMINATION OF WATER FROM CHLORINE PURIFYING APPARATUS.

(Series No. 1)

These tests were made at the pumping station at Fort Myer, Va. The water supplied to the chlorine apparatus had been treated with alum and contained much particulate matter and was turbid, at times quite muddy.

No. of Sample	Date of Collection and Examination, 1911	Tubes containing gas after Incubating 48 Hours			Number of Colonies after 48 Hours			Cl. Used Parts per 1,000,000	Taste or Odor of Chlorine?
		River Water	Water from Mechanical Filter	Water from Cl. Apparatus	River Water	Water from Mechanical Filter	Water from Cl. Apparatus		
1	Feb. 10	50	20	0	1000	300	90	.80	No
2	Feb. 11	50	10	10	170	45	60	1.20	No
3	Feb. 13	0	0	0	160	40	70	6.10	Yes
4	Feb. 14	10	0	0	400	130	75	.50	No
5	Feb. 15	20	0	10	3000	80	50	.50	No
6	Feb. 16	40	0	0	3000	95	75	.50	No
7	Feb. 17	90	0	10	500	0	140	1.00	No
8	Feb. 18	80	20	0	5000	100	100	.75	No
9	Feb. 20	70	0	10	3000	32	46	1.16	No
10	Feb. 21	40	20	10	800	75	60	.70	No
11	Feb. 23	20	10	0	500	175	200	.80	No
12	Feb. 24	10	0	10	1300	100	100	.80	No
Average,		40%	6.6%	5%	1569	97	88		

As stated by the board, "The fact that this water had been treated with alum, operated somewhat to the disadvantage of a chemical sterilizing process, because the particles of sediment, when coagulated by the alum, protected the bacteria contained within the particles to a certain extent from the action of the ozone (nascent oxygen). As will be seen, however, from Table I (Series No. 1), the chlorine apparatus showed a greater reduction of gas-producing and other bacteria than did the very excellent mechanical filter in use for the Fort Myer water supply. The organisms not destroyed were harmless saprophytes, principally spore bearing bacilli (*bacillus subtilis*), which can only be destroyed by prolonged boiling. The bacteriological tests of the water from the apparatus were made in the bacteriological laboratory of the Army Medical School, under the direction of a member of the board, who is chief of the laboratory."

It will be noted that the amount of chlorine used in this series of tests varied from 0.5 of a part to 6.1 parts per million, as determined by titration, and that only in test No. 3, did the water have a taste or odor of chlorine. In this case the excess of chlorine was used in order to see if it were possible to produce absolute sterility. As a matter of fact the result was no better than in numbers 4, 5, and 6,—in which only one-half of a part of chlorine per million was used.

The great variation in bacterial content exhibited by the raw water was due no doubt to the influence of the tide and condition of the river.

TABLE II.

RESULT OF EXAMINATION OF WATER FROM CHLORINE PURIFYING APPARATUS.

(Series No. 2)

The raw water was a mixture of eight parts tap water and one part of river water, obtained near the mouth of a sewer. It contained considerable particulate matter and was quite muddy. Rate of flow through apparatus, 430 gallons per hour.

No. of Sample	Date of Collection and Examination 1911	Percentage of Tubes Containing Gas After 48 Hours		Number of Colonies After 48 Hours		Cl. Used Parts per 1,000,000	Taste or Odor of Chlorine?
		Raw Water	Water from Cl. Apparatus	Raw Water	Water from Cl. Apparatus		
1	March 4	100	0	1100	100	1.00	No
2	March 5	100	10	2500	64	.75	No
3	March 6	100	0	1800	45	.50	No
4	March 7	100	10	2000	98	.50	No
5	March 8	100	0	700	70	.50	No
6	March 9	100	0	700	60	.50	No
7	March 10	100	0	900	80	.40	No
8	March 11	100	0	875	90	.50	No
9	April 3	100	10	500	45	.50	No
10	April 4	100	0	300	75	.50	No
Average,		100%	3%	1137	73		

Again it will be observed that 0.5 of a part of chlorine per million was quite as effective as larger quantities. The surviving bacteria, as in series No. 1, were chiefly *bacillus subtilis.*

TABLE III.

RESULT OF EXAMINATION OF WATER FROM CHLORINE PURIFYING APPARATUS.

(Series No. 3)

The raw water was a mixture of two parts of tap water and one part of river water from near the mouth of a sewer. Considerable particulate matter was present and the water was quite muddy.

Rate of flow through appratus, 430 gallons per hour.

No. of Sample	Date of Collection and Examination 1911	Percentage of Tubes Containing Gas After 48 Hours		Number of Colonies After 48 Hours		Cl. Used Parts per 1,000,000	Taste or Odor of Chlorine?
		Raw Water	Water from Cl. Apparatus	Raw Water	Water from Cl. Apparatus		
1	April 5	100	10	3500	60	.50	No
2	April 6	100	20	1200	50	.50	No
3	April 7	100	20	5000	45	.50	No
4	April 8	100	10	3500	50	.50	No
5	April 10	100	20	2000	100	.50	No
Average,		100%	16%	3040	61		

This series is of interest in that it shows the influence of an excess of organic matter. The raw water contained, presumably, three times as much organic matter and bacteria, as that used in series No. 2. It was muddy and had an offensive odor.

The quantity of chlorine used was one-half of a part per million, which was not enough, for while the bacterial content was reduced to a satisfactory point as shown by the colony count, sixteen per cent. of the tubes showed the presence of the colon bacillus.

The series of tests shown in Table IV, were made in order to determine the efficiency of the method in destroying the colon bacillus in the absence of particulate matter. It will be observed that under the conditions stated four-tenths of a part of chlorine per million was effective although considerable *dissolved* organic matter was present in the water.

TABLE IV.

RESULT OF EXAMINATION OF WATER FROM CHLORINE PURIFYING APPARATUS.

(Series No. 4)

The raw water used for this series of tests was made by contaminating tap water with the filtrate from fresh horse manure; 2-10 cc. of filtrate being added to each gallon.

Rate of flow through apparatus, 430 gallons per hour.

No. of Sample	Date of Examination	Percentage of Tubes Containing Gas After Incubating 48 Hours		Number of Colonies After 48 Hours		Cl. Used Parts per 1,000,000	Taste or Odor of Chlorine?	Remarks
		Raw Water	Water from Cl. Apparatus	Raw Water	Water from Cl. Apparatus			
1	April 13	100	0	1200	50	.40	No	This water contained no particulate matter. The bacteria not destroyed were spore formers chiefly *bacillus subtilus*. Considerable organic matter present in the raw water.
2	April 14	100	0	1200	50	.40	No	
3	April 15	30	0	300	60	.40	No	
4	April 17	20	0	400	50	.40	No	
5	April 18	100	0	300	25	.40	No	
6	April 21	100	0	3000	50	.40	No	
7	April 22	0	0	1200	80	.40	No	
8	April 24	10	0	600	70	.40	No	
Average,		57.5%	0%	1025	55			

TABLE V.

RESULT OF EXAMINATION OF WATER FROM CHLORINE PURIFYING APPARATUS.

(Series No. 5)

Raw water consisted of a mixture of four parts of tap water and one part of river water, obtained from the Potomac River below the mouths of sewers. At times it was very turbid and contained much particulate matter. It was strained through cloth to remove the larger particles.

Rate of flow through apparatus, 430 gallons per hour.

No. of Sample	Date of Examination	Percentage of Tubes Containing Gas After Incubating 48 Hours		Number of Colonies After 48 Hours		Cl. Used Parts per 1,000,000	Taste or Odor of Chlorine?	Remarks
		Raw Water	Water from Cl. Apparatus	Raw Water	Water from Cl. Apparatus			
1	April 25	90	0	3500	160	.40	No	
2	April 26	30	0	4000	110	.40	No	
3	April 27	100	20	1000	80	.40	No	Water very muddy. The organisms surviving were chiefly *bacillus subtilis*. The variations in the raw water were probably due to the tide and state of river.
4	April 28	50	0	1500	70	.40	No	
5	April 29	100	0	6000	60	.40	No	
6	May 1	10	0	2000	20	.40	No	
7	May 2	80	0	2800	85	.40	No	
8	May 3	0	0	5000	60	.40	No	
9	May 4	0	0	2500	100	.40	No	
10	May 5	0	0	1200	90	.40	No	
11	May 6	10	0	1100	150	.40	No	
Average,		42.7%	1.8%	2781	99			

In the first series of tests, made at Fort Myer, the water used was from the pump supplying the mechanical filter. The alum solution used was fed into this pump, and together with the finely divided clay in the water, formed flocculi in which many of the bacteria were imbedded, and were thereby protected from the action of the chlorine. This is believed to account for the presence of the colon bacillus in about five per cent. of the tubes in that series, although more chlorine was used than in series No. 4 in which all the *B. coli* were destroyed.

In the series of tests shown in Table V (page 795), the water was turbid, having in suspension much finely divided clay. It also contained many rather coarse particles which were removed by straining the water through a cloth. Four-tenths of a part of chlorine was used with the result shown in the table.

Having concluded its investigation of the method, the board referred to above summarized its findings and recommendations; from that summary the following extracts are quoted:

"It is the conclusion of the Board that this apparatus offers the following advantages over other methods of water purification now in use:

"(1) Efficiency.—It is believed that the apparatus (method) is as efficient as purification by ozone or by hypochlorite and is more reliable in operation than either.

"(2) Cost of Installation.—The apparatus is exceedingly simple and could be installed in connection with any water supply where the water is pumped into a tank or storage reservoir, at very small cost. * * * * * *

"(3) Cost of Operation.— * * * * * *

The cost of attendance would be very slight, as the apparatus is automatic and only requires the attachment of a new cylinder at infrequent intervals when the supply of chlorine becomes exhausted. * * * * * * ,"

"In view of the advantages which this apparatus is believed by the Board to possess over those now on the market, it is recommended that such an apparatus be installed * * * * at some post where the water is polluted and where no satisfactory system of purification has been installed."

COMPARISON WITH OTHER PURIFICATION METHODS.

In conclusion it may be well to compare this method with other well known means of water purification:

Anhydrous Chlorine and Ozone.

1. The efficiency is practically the same in the two processes.
2. The chlorine apparatus is much more simple and requires no delicate electrical machinery and no complicated mixing apparatus, such as is necessary with ozone.
3. The chlorine method is more reliable in operation and requires less labor.

4. It is also cheaper, costing less than fifty cents per 1,000,000 gallons for chlorine.

5. The chlorine method is applicable to plants of large size, which is not true in the case of ozone as applied at the present time.

Chlorine and Hypochlorites.

1. It is easier to regulate and adjust the quantity of chlorine than it is to regulate the quantity of hypochlorites. The gas is of constant composition, and under a given pressure a definite quantity will always pass through a given orifice in a unit of time, so when once adjusted to the flow of water no further regulation is required.

Hypochlorites, on the contrary, are variable in strength, change rapidly when exposed to air, and require constant care in order to properly regulate the quantity.

2. The chlorine method, the apparatus used being automatic, requires less labor than does the hypochlorite.

3. Since it is easier to regulate the quantity of chlorine than it is to regulate the quantity of hypochlorites, a disagreeable taste and an unpleasant odor are less likely to be imparted to the water when the former is used. It is probable that in this respect the superiority of chlorine is due, in part at least, to the fact that the liquid chlorine has been purified, while the hypochlorite has not.

4. At the present time the hypochlorites cost considerably less than does chlorine, about one-fourth in fact; but if the cost of the extra labor required in the hypochlorite process, and the waste during manipulation be considered, the difference in cost is not so great. Furthermore, it must be remembered that there has heretofore been very little demand for liquid chlorine, and consequently its manufacture has been limited. It is probable that if it were made on a large scale the price would be very much less than it is at present.

Chlorine and filtration.

1. Chlorine is more efficient than filtration in eliminating pathogenic organisms.

2. It is cheaper to install a chlorine purifying plant than a filter plant.

3. A chlorine plant is cheaper to operate because the labor required is so much less.

4. In the chlorine method no provision is made for clarifying the water, hence, for plants other than those drawing their supply from lakes or wells, it will usually be necessary to have sedimenting reservoirs or rough filters to clarify the water either before or after the application of the chlorine.